EXECUTIVE SUMMARY: COMPARISON OF STORM RESPONSE OF STREAMS IN SMALL, UNMINED AND VALLEY-FILLED WATERSHEDS, 1999-2001, BALLARD FORK, WEST VIRGINIA

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Abstract: Peak unit flows following summer storms with rainfall exceeding about one inch per hour, approximately the one-year return period, were greater from a watershed comprised of a mountaintop-removal coal mine (Unnamed Tributary) than from an unmined watershed (Spring Branch) in the Ballard Fork watershed in West Virginia. Following all storms with rainfall intensity of about 0.25 in. per hour or more, the storm hydrograph from the Unnamed Tributary watershed showed a sharp initial rise, followed by a decrease in flow, then a delayed secondary peak of water that had apparently flowed through the valley fill. One storm that produced less than an inch of rain before the secondary peak from the previous storm had receded caused peak unit flow from the Unnamed Tributary to exceed peak unit flow from Spring Branch. Peak unit flow from the Unnamed Tributary was less than peak unit flow from Spring Branch following slow, soaking rains. No storms during this study produced 1-hour or 24-hour rainfall in excess of the 5-year return period, and flow during this study never exceeded the 1.5-year return period. Runoff patterns from the Unnamed Tributary watershed appear to be influenced by the compaction of soils on the mine, by the low maximum infiltration rate into the valley fill compared to the forested watershed, by storage of water in the valley fill, and by the absence from the mine of interception from trees and leaf litter.

Introduction: The U.S. Geological Survey (USGS) began a study of the effects of on flow of surface mines using valley fills in the Ballard Fork watershed, in the upper Mud River basin near Madison, W.Va., in November 1999. Three continuous flow-gaging stations were installed. One gage was located on an Unnamed Tributary to Ballard Fork, directly downstream from a valley fill, and upstream from the sediment pond. The entire watershed of this stream (0.19 mi^2) is within an area permitted for mining, and all but a few acres is mined. The second gage, near the mouth of Spring Branch, drains an unmined, forested watershed (0.53 mi^2). The third gage was located on the main stem of Ballard Fork, which drains an area (2.12 mi^2) that includes both the Unnamed Tributary and Spring Branch watersheds. The entire Ballard Fork watershed is either surface mined or forested, although the forested areas contain some pipelines and all-terrain vehicle trails that probably affect rainfall-runoff relations. Forty percent of the Ballard Fork watershed is within areas that had been permitted for mining, although less (about 30 percent) of the watershed was actually mined. About 44 percent of the Unnamed Tributary and 12 percent of the Ballard Fork watershed is covered by valley fills.

Four rain gages were used during this study to collect precipitation data. Two rain gages were operated in mined areas on mountaintops, and the other two were in open areas on the valley floor. Precipitation amounts reported in this document are the average of amounts recorded at these four rain gages.

Mines in the Ballard Fork watershed received a Phase 1 bond release in August 2000, although mine inspection forms filed since November 1997 estimated that grading and backfilling was complete on all but 10 acres. The mined areas was sparsely covered with grasses, other herbaceous vegetation, and small trees typical of a newly reclaimed surface mine. Forest in Spring Branch and the rest of Ballard Fork was second- or third-growth, and dominant canopy species included white and red oak, several hickory species, sycamore, and tulip poplar.

Precipitation: Greatest average 1-hour total precipitation recorded at the four rain gages (1.63 in., standard deviation = 0.11 in.) during the study period was July 26 between 3:30 p.m. and 4:30 p.m. The greatest 24-hour total precipitation (3.16 in., standard deviation = 0.24 in.) during the study was during the same storm, between 1:00 a.m. July 26 and 1:00 a.m. July 27. The return period for both the 1-hour and 24-hour rainfall from this storm was between two and five years. Average 1-hour precipitation exceeded 1.1 in. (about the 1-hour, 1-year rainfall) on June 6, 2001, and average precipitation plus one standard deviation exceeded 1.1 in. on June 21, 2000, and August 12, 2001. Average 24-hour rainfall exceeded 2.0 in. (about the 24-hour, 1-year rainfall) during one other storm, on November 26, 1999, and average precipitation plus one standard deviation exceeded 2.0 in. during three other storms during the study period.

Most of the intense rainfall in the Ballard Fork watershed during this study fell during summer thunderstorms. Of the 10 largest 1-hour average rainfalls, eight were during May through September, and six of these storms were during June and July. The largest 24-hour total rainfalls were generally recorded in the summer, as well; eight of the ten highest 24-hour rainfall totals were recorded during May, June, or July. In general, rainfall recorded by the Sally Fork Mountaintop rain gage, in the Unnamed Tributary watershed, was less than rainfall recorded at the other three rain gages; for the ten storms with the highest 1-hour rainfall, the Sally Fork Mountaintop rain gage reading was less than the average eight times.

Peak flows: Maximum instantaneous flow during the study period was 8.9 ft^3/s for the Unnamed Tributary (July 26, 2001), 87 ft^3/s for Ballard Fork (May 18, 2001), and 34 ft^3/s for Spring Branch (February 19, 2000). Instantaneous flow recorded during the study period did not exceed the 1.5-year return period at any site.

Peaks with unit flow greater than 20 $ft^3/s/mi^2$ were recorded five times at the Unnamed Tributary, eleven times at Spring Branch, and nine times at Ballard Fork. All three gages recorded flows in this range during four of the five storms, which raised unit flow in the Unnamed Tributary above 20 $ft^3/s/mi^2$, although the Spring Branch gage was not operating during the fifth storm, of May 18, 2001.

Storm response: Response of the Unnamed Tributary to different types of storms was distinctly different from response of Spring Branch and Ballard Fork. Spring Branch and Ballard Fork generally rose when total moisture in their watersheds increased. These streams generally peaked shortly after rainfall ended, and quickly receded.

In contrast, the Unnamed Tributary's storm hydrograph typically showed a double peak when rainfall intensity exceeded about 0.25 in./hour. The hydrograph of November 26-27, 1999, shows this pattern clearly (fig. 1). Total rainfall for this storm exceeded 3.0 in., and much of it

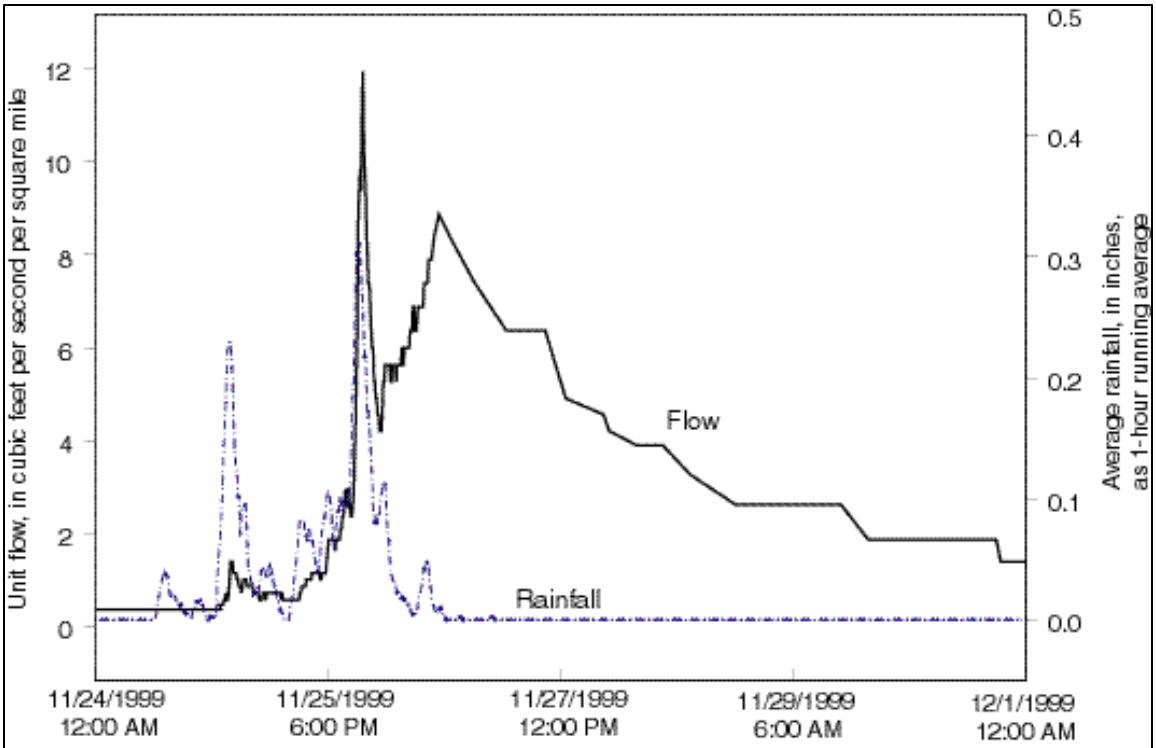

Figure 1. Storm hydrograph at Unnamed Tributary of Ballard Fork near Mud, W.Va., and rainfall, as a 1-hour running average, for four rain gages in the Ballard Fork watershed.

fell as a slow, soaking rain; the maximum one-hour rainfall recorded at any rain gage was 0.48 in. Antecedent conditions were dry; the rain of November 24 was the first since November 2. Although the rain fell in two major bursts, the storm hydrograph had the same shape typical of storms in which rain fell in only one major burst. About 0.73 in. of rain fell on November 25-26 between 9:30 p.m. and 3:30 a.m. When rain was received with an intensity of about 0.3 in. per hour at about midnight on November 26, the infiltration capacity of the watershed was apparently exceeded, causing a sharp peak in flow. This peak quickly receded when rain intensity decreased, but the delayed flow of water that had apparently flowed through the valley fill continued to increase and peaked at 2:00 p.m. on November 26, eight hours after the last rain fell that exceeded 0.10 in./hour.

During most storms, peak unit flow from Spring Branch and Ballard Fork exceeded peak unit flow from the Unnamed Tributary, despite the effects of interception on runoff in the forested watersheds. However, in the two most intense storms during the study period, on June 6, 2001 (maximum average one-hour rainfall = 1.24 in.) and July 26, 2001 (maximum average one-hour rainfall = 1.63 in.), maximum runoff from the Unnamed Tributary exceeded maximum runoff in the forested watersheds. Both of these storms took place in midsummer, when rainfall interception by trees is at its maximum. In the third most intense storm during the study period, June 21, 2000, the gage at the Unnamed Tributary malfunctioned, so relative unit flows from this storm are unknown.

In the storm of July 26, 2001, intense rain apparently exceeded infiltration capacity of the Unnamed Tributary watershed and led to sharp peak in flow that exceeded unit flow at the other two gages (fig. 2). Antecedent conditions to the July 26 storm were moderate; the Ballard Fork watershed received nearly 0.50 in. of rain the afternoon of July 22. The initial substantial rain (maximum rainfall intensity = 0.25 in./hour) beginning about 7:00 a.m. on July 26 did not cause a runoff response from any stream.

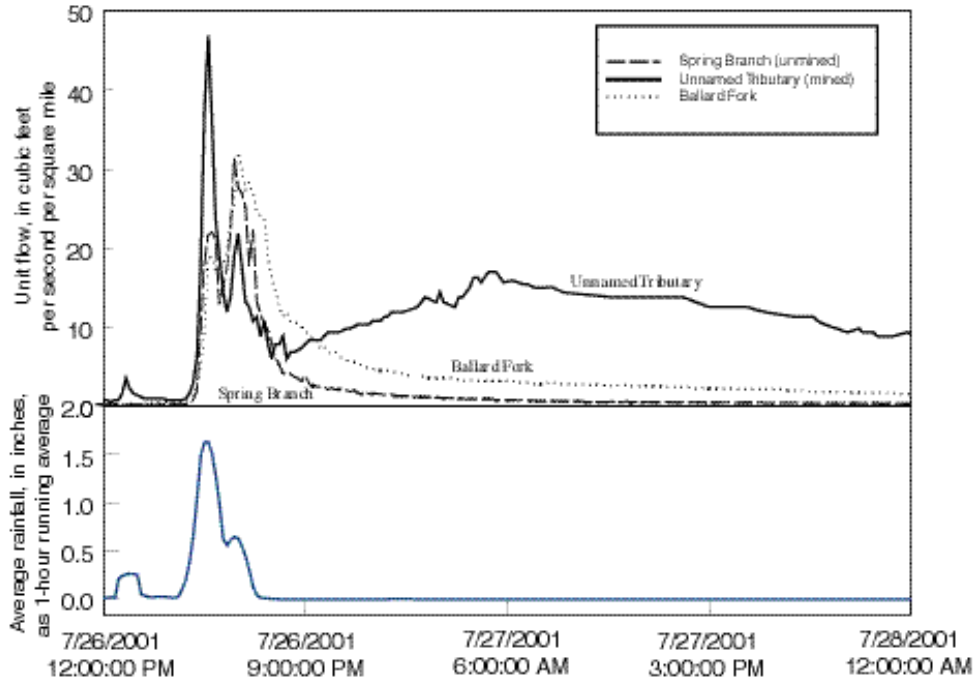

Figure 2. Storm hydrograph for July 26-28, 2001, for three stream gages, and rainfall, as a 1-hour running average for four rain gages, in the Ballard Fork watershed.

The most intense rainfall recorded during this study was received between 3:50 p.m. and 4:30 p.m. on July 26, more than 1.3 in. The Unnamed Tributary rose sharply in response to this rain, and peaked at 4:40 p.m., while rain was still falling but after intensity had decreased. Maximum unit flow for the Unnamed Tributary was 46.9 $ft^3/s/mi^2$. Although the two other watersheds responded to this burst of rain, their peaks were later in the evening, at about 6:00 p.m., at the end of a final spate of rain of 0.63 in./hour. The Unnamed Tributary responded less strongly to the final rain than it had to the earlier, more intense rain, with a maximum unit flow on the second peak of 21.8 $ft^3/s/mi^2$. The initial peak on the Unnamed Tributary receded as quickly as Spring Branch and more quickly than Ballard Fork, but about 8:30 p.m., a secondary peak began on the Unnamed Tributary, apparently of water that had flowed through the valley fill. This attenuated secondary peak reached a maximum unit flow of 19.1 $ft^3/s/mi^2$ at 6:20 a.m. July 27, several hours after Spring Branch and Ballard Fork had largely receded.

Peak unit flow from the valley fill exceeded peak unit flow from the other watersheds on July 29, when rainfall of unexceptional intensity (maximum one-hour rainfall = 0.82 in.) was received before a secondary peak on the Unnamed Tributary had receded. Rain on July 28 caused small initial rises on all three streams. When a hard rain fell on the afternoon of July 29, the peaks on Spring Branch and Ballard Fork had receded, but the Unnamed Tributary was still rising from delayed flow from July 28.

Discussion: Runoff patterns from the Unnamed Tributary watershed appear to be influenced by compaction of soils on the mine, by the low maximum infiltration rate into the mine and valley fill compared to the forested watershed, by storage of water in the valley fill, and by the absence of interception from trees and leaf litter on the mine. Soils on mined areas are typically heavily compacted to prevent erosion, which decreases infiltration capacity. Hortonian (excess overland) flow appears to be important in the Unnamed Tributary watershed following intense storms, and to cause the initial peak on the rising arm of storm hydrographs; Hortonian flow is rare in the eastern U.S. except from urban or other highly disturbed watersheds. The initial sharp peak, the part of the hydrograph that is apparently Hortonian flow, appears following storms with intensity greater than about 0.25 in./hour.

Typical canopy interception rates in eastern hardwood forests are about ten per cent of gross rainfall, and dry leaf litter may intercept several tenths of an inch of water that falls through the canopy. Water that would have been retained by these processes in the Spring Branch watershed was available to run off the Unnamed Tributary watershed. Because of these factors, unit flow from the mined watershed exceeded unit flow from the unmined watershed during storms when rainfall exceeded about 1 in./hour, suggesting that mountaintop removal mining is

likely to increase flooding from intense summer thunderstorms. Once during this study, peak unit flow from the Unnamed Tributary watershed exceeded runoff from the Spring Branch watershed because a hard rain was received before the delayed secondary peak on the Unnamed Tributary had receded. This suggests that mountaintop removal mining is especially likely to increase flooding during summer storm systems that last several days.

A large proportion of storm water received in the Unnamed Tributary watershed runs off during a period 8 to 48 hours after rain stops, compared to 0 to 4 hours in the Spring Branch watershed. Comparison of total volume running off from three selected storms showed that (1) total unit flow during all three storms was greatest from the Unnamed Tributary, (2) for the Unnamed Tributary, flow during recessions exceeded storm runoff during all three storms, although for Spring Branch, storm runoff exceeded flow during recessions in two storms, and (3) total unit flow as storm runoff from the Unnamed Tributary was typically less than unit storm runoff from Spring Branch and Ballard Fork. Although most of the water running off the Unnamed Tributary watershed comes in this delayed flow, the overall peak for most storms is the sharp, initial peak.

Peak unit flow from a storm is expected to be greater from a smaller watershed, if all land-use and other characteristics are identical. In this study, peak unit flow from the Spring Branch watershed usually exceeded peak unit flow from the Unnamed Tributary watershed, and was usually about the same as peak unit flow from the overall Ballard Fork watershed. Rainfall-runoff relations on altered landscapes are site-specific and mining and reclamation practices that affect storm response may vary among mines.

Source: Messinger, Terence, 2003, Comparison of storm response of streams in small, unmined and valley-filled watersheds, 1999-2001, Ballard Fork, West Virginia: U.S. Geological Survey Water-Resources Investigations Report 02-4303.